AD-A069 735 RESOURCE ENGINEERING AND PLANNING CO HUNTSVILLE AL F/G 14/2
RADIATED FIELD SUSCEPTIBILITY TASKS.(U)
JUN 77 G L BROWN DAAH01-76-C-0236
UNCLASSIFIED REAP-FR-0236 NL

1 OF 1
AD
A069 735

END
DATE
FILMED
7-79
DDC

Report REAP FR-0236

LEVEL II

RADIATED FIELD SUSCEPTIBILITY TASKS

Glenn L. Brown
Resource Engineering And Planning Company
2604 Vista Drive, S.E.
Huntsville, Alabama 35803

24 June 1977

Final Report for Period 30 September 1975 - 24 June 1977

Approved for public release; distribution unlimited

Prepared for

U.S. Army Missile Research And Development Command
Redstone Arsenal, Alabama 35809

AD A069735

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
14 REAP-FR-Ø236

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
6 RADIATED FIELD SUSCEPTIBILITY TASKS.

5. TYPE OF REPORT & PERIOD COVERED
9 Final Rep[redacted]t,
30 Sep[redacted]75 — 24 Jun[redacted]77,

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
10 Glenn L. Brown

8. CONTRACT OR GRANT NUMBER(s)
15 DAAHØ1-76-C-Ø236

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Resource Engineering And Planning Company
2604 Vista Drive S.E.
Huntsville, Alabama 35803

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
U.S. Army Missile Research & Development Command
Redstone Arsenal, Alabama 35809

12. REPORT DATE
11 24 Jun[redacted]77

13. NUMBER OF PAGES
~~28~~ 12 28p.

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Electromagnetic fields
Radiated fields
Missile susceptibility
Transfer function

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

→ Problems associated with the generation of valid test environments at the electromagnetic effects test facilities of the U.S. Army Missile Command are identified and methods of improvement described. Equipment and procedures for measuring the spatial characteristics and intensity of test fields are described. Recommendations for improvements in facilities and susceptibility assessment methodology which will effect a significant decrease in the time and cost of susceptibility programs are presented.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

SR 392782

TABLE OF CONTENTS

1.0 INTRODUCTION

A review has been conducted of the electromagnetic susceptibility test facilities at the U.S. Army Missile Command. Problems associated with the generation of valid test environments were identified and methods of improvement recommended. Test programs and procedures for measuring the spatial characteristics and intensity of the test field were developed. An evaluation of the effectiveness of present test facilities was undertaken and recommendations made for improvements in facilities and methodology which will effect a significant decrease in the time and cost of susceptibility programs.

2.0 FIELD MAPPING AND FIELD CALIBRATION AT THE ELECTROMAGNETIC EFFECTS TEST FACILITY

2.1 General

Two types of missile system susceptibility tests are conducted at the Electromagnetic Effects (EME) Test Facility. In-flight tests are performed to investigate the response of a missile to electromagnetic environments after launch. On-launcher tests involve the exposure of a complete fire unit, with missiles on the rails, to prescribed electromagnetic sources. The characteristics of the electromagnetic environments are considerably different for the two types of tests. A missile in flight can be expected to encounter essentially plane wave free space fields while fire units will experience ground-interacted fields with significantly different spatial characteristics. In both types of tests, it is necessary to map the field in the test volume to verify that the spatial characteristics of the test field adequately simulate a specified real life situation. It is also necessary to provide a means of determining the magnitude of the field impinging on the test article. Field mapping procedures and results, and field calibration methods, for both in-flight and on-launcher tests, are described in the following paragraphs.

2.2 In-Flight Tests

In-flight tests have been conducted over the frequency range from 50 MHz to 18 GHz. A permanently mounted log periodic (LP) antenna was used to generate the test field for the frequency range 50 MHz to 350 MHz. A ridged horn antenna was used from 350 MHz to 1.2 GHz, and a series of standard gain horns were used from 1.2 GHz to 18 GHz. The test areas are located near Building 8975 at Redstone Arsenal. Power generation equipment and data processing and recording instrumentation are located inside Building 8975. Table 1 lists the antennas and transmitter power available over the various frequency ranges.

The electromagnetic environment at all EME Susceptibility Facilities differs from an in-flight threat environment in at least two respects. The gradient of the test field is greater than that of the threat field and the phase front curvature of the test field is greater than the threat field curvature.

An in-flight threat environment is produced by radiating sources which are at large distances (a large number of wavelengths) from the missile

Table 1 Test capabilities at open air facility

Frequency range	Antenna	Gain	Transmitter Power
50-350 Mhz	log periodic	5 - 6	5 KW
350MHz - 1.2 GHz	ridged horn	6 - 7	50 watts
1.2 GHz - 18 GHz	series of standard gain horns	30 - 60	20 watts

over most of the flight path. Thus the threat environment is essentially a plane wave, free space, electromagnetic field. At a test facility it is desirable to bring the missile as close to the radiating antenna as permissible to avoid the need for extremely high transmitter powers. It is usual practice to require that the missile-antenna separation distance be large enough that the missile is in the "radiation field" of the antenna where the field intensity decreases as the inverse first power of separation distance and the field impedance is very nearly that of a plane wave. When this criterion is satisfied, however, there still remains the fact that the missile is closer to the antenna than in the threat situation and therefore the field gradient and phase front curvature are both larger than for the threat field.

A "far field" criterion which is used in measuring antenna patterns, where field curvature at the test dipole is the major concern, is that the requisite far field range, R is

$$R=2W^2/L$$

where W is the test object (dipole) length and L is the electromagnetic wave length. This criterion limits the effect of phase front curvature to 22.5 degrees of phase change along the test object length and assures excellent accuracy for antenna pattern measurements. However, at high frequencies, the far field distance becomes very large. For example, R would be 600 meters for a 3 meter long missile at a test frequency of 10 GHz. This requirement can not be met at any existing EME susceptibility facility. Furthermore, this criterion was established without concern for field gradient effects.

In order to insure that valid susceptibility data is obtained at the MICOM facility, a recommendation was made that an analysis be conducted to provide a better understanding of the effect of missile-antenna separation distance on missile response.

A contract was let by MICOM with Dr. L. Tsai of the University of Mississippi to conduct a theoretical investigation of the effect of field gradients and phase front curvature on the response of a missile to an electromagnetic environment. Dr. Tsai modeled the missile with a conducting cylinder, no appendages, and calculated the skin currents produced on the missile by the field from an electric dipole source at various distances from the missile. He also calculated the skin currents produced by a plane wave field striking the missile at the same angle as the dipole field. Calculations were made for the field striking the missile at near grazing angles, where the field gradient should be the principal effective difference between the dipole field and the plane wave. Calculations were also made for the field striking the missile at angles near broadside where phase front curvature should be the principal effective difference between the dipole field and the plane wave. The criteria for selecting a minimum missile-antenna separation distance is that the distance should be great enough that the skin currents produced by the antenna field are essentially the same in amplitude and distribution as would be produced by a plane wave field. Dr. Tsai's calculations show that, over the frequency range covered by the LP antenna (50 MHz to 350 MHz), the missile-antenna separation distance for a ten foot long missile should be a least forty feet for

the peak missile currents produced by the dipole antenna field to be within 10% of the peak missile currents produced by a plane wave field. This distance was therefore specified as a minimum separation distance for tests in the LP frequency range.

An interesting result was observed for fields incident on the missile at near grazing angles. The current amplitude was found to be larger near the far end of the missile than near the closer end. The implication is that if the port of entry into the missile is near the front of the missile, an electromagnetic field arriving from the rear of the missile would cause larger interior currents than one arriving from the front.

The results obtained for a 3 meter missile can be scaled and applied to missiles of different length. For example, if a missile is 1 meter long, the missile-antenna separation distance should be at least 13.3 feet at test frequencies between 300 and 600 MHz.

The validity of the results obtained by Dr. Tsai is limited to frequencies at which the free space wave length is small compared to the missile diameter. Hence, for a five inch diameter missile, this work provides no criterion for missile-antenna separation distances at frequencies greater than 350 MHz. Separation distances for tests involving use of the ridged horn antenna or a standard gain horn were therefore specified on the basis of transmitter power available and the field strength required at the missile.

At the EME test facility the radiating antenna is mounted at a height of twelve feet above an asphalt test area and the missile is mounted on a non-conducting low-dielectric pedestal at the same height as the antenna. The pedestal is mounted on a rotatable base. In order to produce an electromagnetic environment at the missile which adequately simulates a plane wave environment, it is necessary not only to make the missile-antenna separation distance large enough, but also to suppress the field reflected from the asphalt. This is done by placing diffraction screens between the missile and the antenna in the proper locations to intercept and backscatter the reflected field away from the volume occupied by the missile. Diffraction screens will not entirely eliminate reflected fields at the missile but the magnitude of the reflected field can be reduced to a small percentage of the direct field. Placement of the screens is largely done by cut and try since the fields do not reflect from one point but rather from regions defined by fresnel zones. Field mapping of the test volume to be occupied by the missile is necessary to the process of adjusting the screens until the reflections have been reduced to an acceptable level. At the EME facility, the goal was to reduce the reflected field to 20 db below the direct field.

2.2.1 Log Periodic Antenna Test Range

The location chosen for the missile stand is 60 feet from the LP support pole with the center of the top of the missile pedestal on the axis of the LP beam. This places the center of the missile at a distance of approximately 45 feet from the radiating element at 300 MHz and greater than 45 feet at lower frequencies. With the missile stand in place, but with the missile removed, the field in the vicinity of the top of the missile stand

was mapped to insure that the required degree of field uniformity was achieved. The diffraction screens were adjusted to reduce reflected field amplitudes to 20 db below the direct field amplitude. The position of the diffraction screens to achieve this degree of reflective suppression was found by cut and try methods to be 26' 3" from the LP pole for the frequency range 50 MHz to 130 MHz, and 43 feet from the LP pole for the frequency range 130 MHz to 350 MHz. The screens are 6 feet high and 8 feet wide, constructed of thin wire mesh (copper window screen) attached to wooden frames. Four screens are located side by side, forming a 32 foot long diffraction screen perpendicular to the line from the missile stand to the base of the log periodic antenna.

Field mapping was accomplished by mounting a tuned dipole probe on a wooden traversing structure so constructed as to hold the probe at a fixed height above the earth and, upon excitation of an electric motor, move the probe horizontally in a straight line for a distance of ten feet (see figure 1). The probe was connected by coaxial cable to a power meter located at the base of the structure, and the DC output of the power meter was connected to the Y axis of an XY plotter located inside Building 8975. The X axis of the plotter was connected to a potentiometer mounted to the traversing structure. The X axis voltage was thus proportional to the distance the probe moved, and the Y axis voltage was proportional to the magnitude of the field power density. The traversing structure was first adjusted so the probe moved along the center of the top of the missile support stand with the missile removed from the stand. Transmitter power was held constant during the run. In the absence of reflections, the graph traced out on the XY plotter should be a smooth line with height (magnitude of field power density) proportional to the inverse square of the distance of the probe from the antenna. The presence of reflected fields was evidenced by periodic fluctuations about the $1/r^2$ curve. This is shown in figure 2, a data plot made with the LP antenna polarized horizontally. The magnitude of the reflected field, in db relative to the direct field, is given by the equation

$$P_r \text{ (db)} = \log (P_m{}^{1/2} - P_d{}^{1/2}) - 20 \log P_d{}^{1/2}$$

where P_m is the magnitude of the measured power density at a probe position where the field plot deviates the most from the $1/r^2$ curve, and P_d is the power density, at the same point, from the $1/r^2$ curve. From the data plot of figure 2, it is seen that at frequencies around 100 MHz the reflected field magnitude was 25 db below the direct field magnitude.

After mapping the contour of the field along the center of the missile stand, field contour maps were made at four feet to the left and at four feet to the right of the stand. Mapping traverses were then made at the front and rear of the missile stand with the probe moving across the field rather than down field. Mapping was carried out for both vertically and horizontally polarized fields over the frequency range from 50 MHz to 350 MHz. With the diffraction fences at 26' 3" from the LP pole for the frequency range 50 MHz to 130 MHz, and 43' from the LP pole for the frequency range 130 MHz to 350 MHz, reflected fields were found to be at least 20 db lower

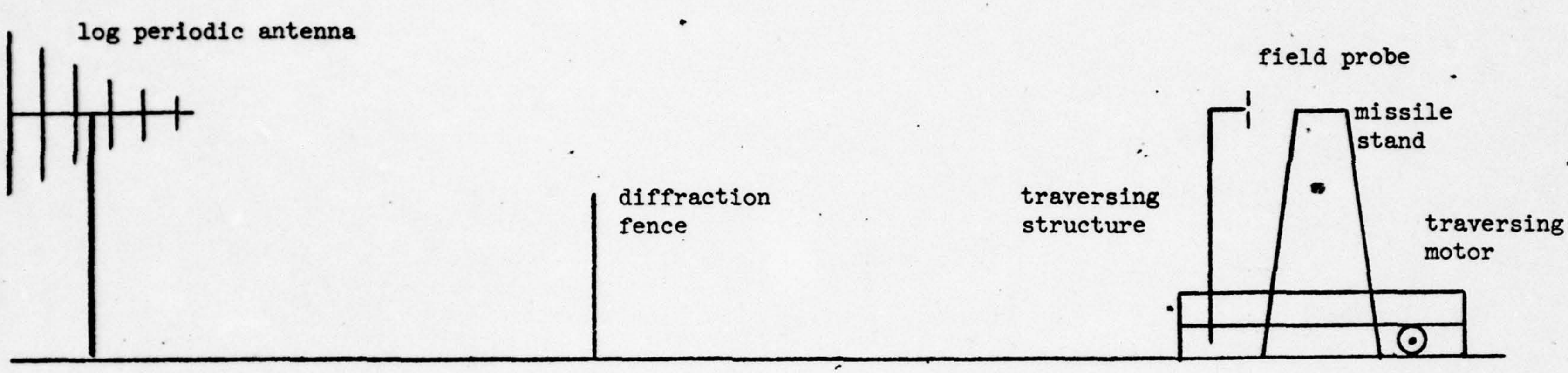

Figure 1 Field mapping set up

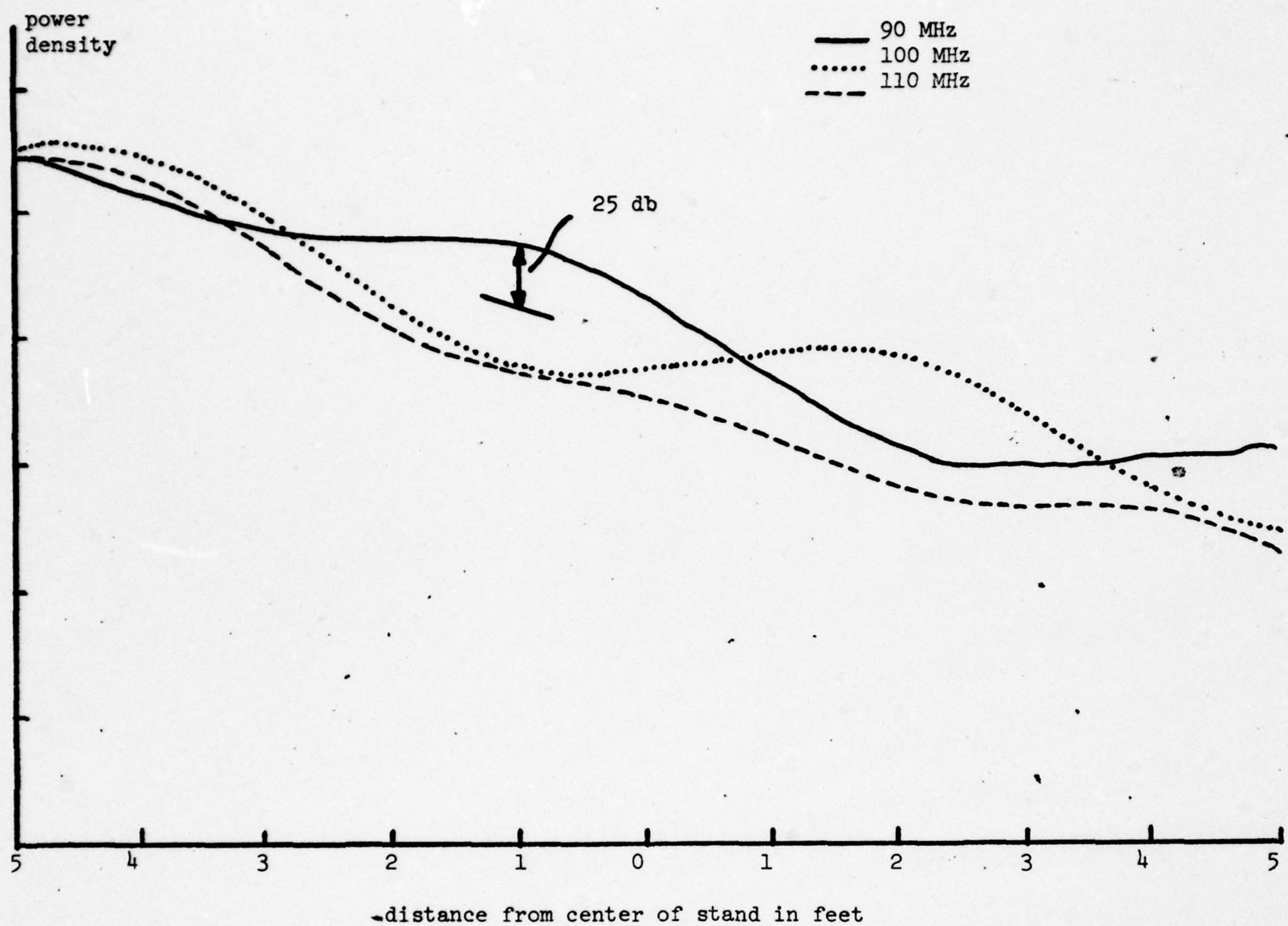

Figure 2. Field map, horizontal polarization

in magnitude than direct fields.

A field calibration and monitoring system was established at the LP test site by locating two reference B dot field sensors near the log periodic antenna at a distance of approximately 43 feet from the missile stand. These sensors are permanently mounted in a fixed position. Tests were conducted to insure that the field in the vicinity of the sensors was not perturbed when the missile was placed on the stand. The two sensors are oriented to measure the horizontal and vertical components of the radiated field. The outputs of the sensors are fed by coaxial cable to a power meter located in the transmitter room of building 8975. The d.c. voltage from the power meter, which is a measure of the field intensity at the test site, is recorded on one channel of the magnetic tape record of the missile monitor points, on one channel of the strip chart record, and drives the X axis of the XY plotter record of missile monitor point response. The system was calibrated by locating a Bureau of Standards E field probe on the missile stand and bringing up the transmitter power until a field strength of 10 volts per meter was reached. The output of the B dot power meter was then recorded. This provided the calibration constant which relates the B dot power meter reading to the electric field intensity at the missile stand. If P is the power meter reading in milliwatts, then the field intensity E in volts per meter is $E = kP^{1/2}$ where k is the calibration constant. The system was calibrated for both vertical and horizontal fields at every 10 MHz over the log periodic antenna frequency range. The values of k, for the missile stand at 60 feet from the LP support pole and for the diffraction fences at the positions previously given, are tabulated in table 2. These values of k will give the field strength of an unmodulated field. In the case of a pulse modulated field, the field strength value calculated using k from table 2 will be an effective field strength. The average power density of a pulse modulated field is given by the equation

$$P_a = E^2/377$$

where P_a is the average power density in watts per square meter and E is the effective field strength. The peak power density, P_p is

$$P_p = P_a/d$$

where d is the duty factor. The peak field intensity, E_p is

$$E_p = E/d^{1/2}$$

Table 2 Calibration factors for LP antenna test range

FREQUENCY (MHz)	k VERTICAL POLARIZATION	k HORIZONTAL POLARIZATION
40	11.70	30.15
50	17.15	22.94
60	15.43	17.67
70	13.87	17.15
80	14.59	10.54
90	14.14	8.16
100	11.32	8.64
110	8.28	9.90
120	6.98	8.06
130	10.80	7.39
140	8.77	6.70
150	8.87	6.32
160	8.94	6.74
170	10.66	5.87
180	9.85	6.59
190	11.62	4.66
200	9.90	5.63
210	9.62	6.45
220	11.70	6.74
230	11.87	6.59
240	11.18	4.71
250	10.78	6.59
260	10.98	5.42
270	13.02	6.08
280	12.13	5.42
290	13.87	5.98
300	12.13	5.87
310	13.48	5.42
320	10.85	5.42
330	13.02	5.13
340	11.47	5.27
350	17.41	5.50

2.2.2 Ridged Horn Test Range

A ridged horn antenna is used for generating the test fields over the frequency range from 350 MHz to 1.2 GHz. The test site for this frequency range is located on an asphalt pad at the west side of building 8975. The missile support stand is located approximately thirty feet from the side of the building. The antenna stand supports the ridged horn antenna at the same height as the missile (twelve feet). The transmitter and power monitoring equipment is located on the antenna stand which is mounted on wheels and moved into building 8975 when tests are not in progress. During testing, the antenna stand is secured in position by two steel rods, one each at the front and back of the stand, which extend from holes in the frame of the stand down into holes in the black top. The locations of the missile and antenna stands were chosen to minimize the effect of reflections from structures in the vicinity of the test area and to allow for illumination of the missile over an aspect angle range of 180 degrees while the missile is tracking a mobile target.

The requirement on field intensity over this frequency band is an average power density of .26 watts per square meter at the missile (effective field strength of 10 volts per meter) with a 25% duty factor. The ridged horn antenna has a gain of about 5 at the lower end of the band. The maximum transmitter power available at the present time is 50 watts (higher power transmitters are being procured). In order to meet the field strength requirements, with this antenna gain and transmitter power, the antenna cannot be more than 15 feet from the missile. The antenna location at the test site was thus established at fifteen feet from the center of the missile support stand. This provides for the desired field strength at the center of the missile but there is a significant field gradient along the missile length for head on illumination. In the case of a ten foot long missile the field strength at the front of the missile, with head on illumination, will be twice as large as the field strength at the rear of the missile. This gradient problem can be reduced when higher power transmitters have been acquired by increasing the missile-antenna separation distance.

A field mapping program was conducted to measure the magnitude of fields reflected into the test volume by scattering from surrounding structures and from the earth, and to reduce the reflected fields by the introduction of diffraction fences if required. This was accomplished by mounting a B dot probe on the same traversing structure used to map the LP test area. As before, the probe was connected to a power meter and the DC output of the power meter was connected to the Y axis of an XY plotter. The X axis of the plotter was connected to a potentiometer mounted to the traversing structure.

Field power density plots were made for both horizontally and vertically polarized fields at every 100 MHz from 350 MHz to 1250 MHz. With two diffraction screens, each 6 feet high and 8 feet long, installed side by side to form a 16 foot screen between the antenna and the missile stand at a distance of 95 inches from the antenna feed point, reflections along the center line of the top of the missile stand were in all cases down 20 db from the direct field. The B dot probe was then moved out 31" from the missile stand center line and the measurements were repeated. Due to being out of the center of the antenna beam, the reflected fields were more significant. However, reflected fields were still 20 db or more down at most frequencies

and polarizations. The largest reflected field observed was 14 db down from the direct field. Field calibration was accomplished by placing a calibrated B dot probe at the top center of the missile stand and adjusting the transmitter power to produce a 20 volt per meter unmodulated field at the probe. The magnitudes of the foreward and backward antenna powers were then recorded. Because the transmitter power does not exceed 50 watts over this frequency range, non linearities in couplers, connectors, and cables is not a matter of concern. It is therefor not necessary to install reference field sensors as in the case of the LP test area calibration. The equipment set up is shown in figure 3.

The calibration procedure was repeated every 20 MHz over the frequency range from 340 to 1200 MHz for vertical, horizontal, and 45 degree field polarization. A calibration factor k, which relates the effective field strength at the center of the missile stand to the average foreward antenna power, was calculated for each case. The effective field strength, E, at any transmitter setting can be calculated from the equation

$$E= kP^{1/2}$$

where P is the foreward antenna power. The calibration factors for this test configuration are given in table 3.

2.2.3 Standard Gain Horn Test Range

Standard gain horns are used to generate the test environment over the frequency range from 1.2 to 18GHz. The test site for this frequency range is the same as the Ridged Horn test site. The horns are mounted, one at a time, on an antenna stand which places them 12 feet above the asphalt. The missile stand is the same as that used for the LP and Ridged Horn tests. The standard gain horns used over this frequency range are tabulated in table 4.

Field intensity requirements over this frequency range required an average power density of .26 watts per square meter (effective field strength of 10 volts per meter) with a pulse modulated field of 25% duty factor.. Each standard gain horn has a gain of 20 or greater, depending upon the frequency. The transmitters which drive the horns can produce 20 watts, or greater, again depending upon the frequency. In order to meet the field strength requirements, with this antenna gain and transmitter power, the antenna cannot be more than 18 feet from the missile. The antenna location for missile tests in this frequency regime was thus established at 18 feet from the center of the missile support stand. The missile stand was at the same location as for the Ridged Horn tests, and the antenna stand was moved directly back three feet from its Ridged Horn test location.

Field mapping measurements were carried out in the same manner as for the LP and Ridged Horn facilities. The field sensing probe for this frequency range was a SANDIA X200 dipole probe working into a high input impedance volt meter. Hence field strength rather than power density is recorded on the XY plotter. This probe is calibrated up to 10 GHz but can be used up to 18 GHz to make relative field measurements. In the frequency band from 12 to 18 GHz, a standard gain horn was used as a field probe to check the results obtained with the SANDIA probe. The standard gain horn

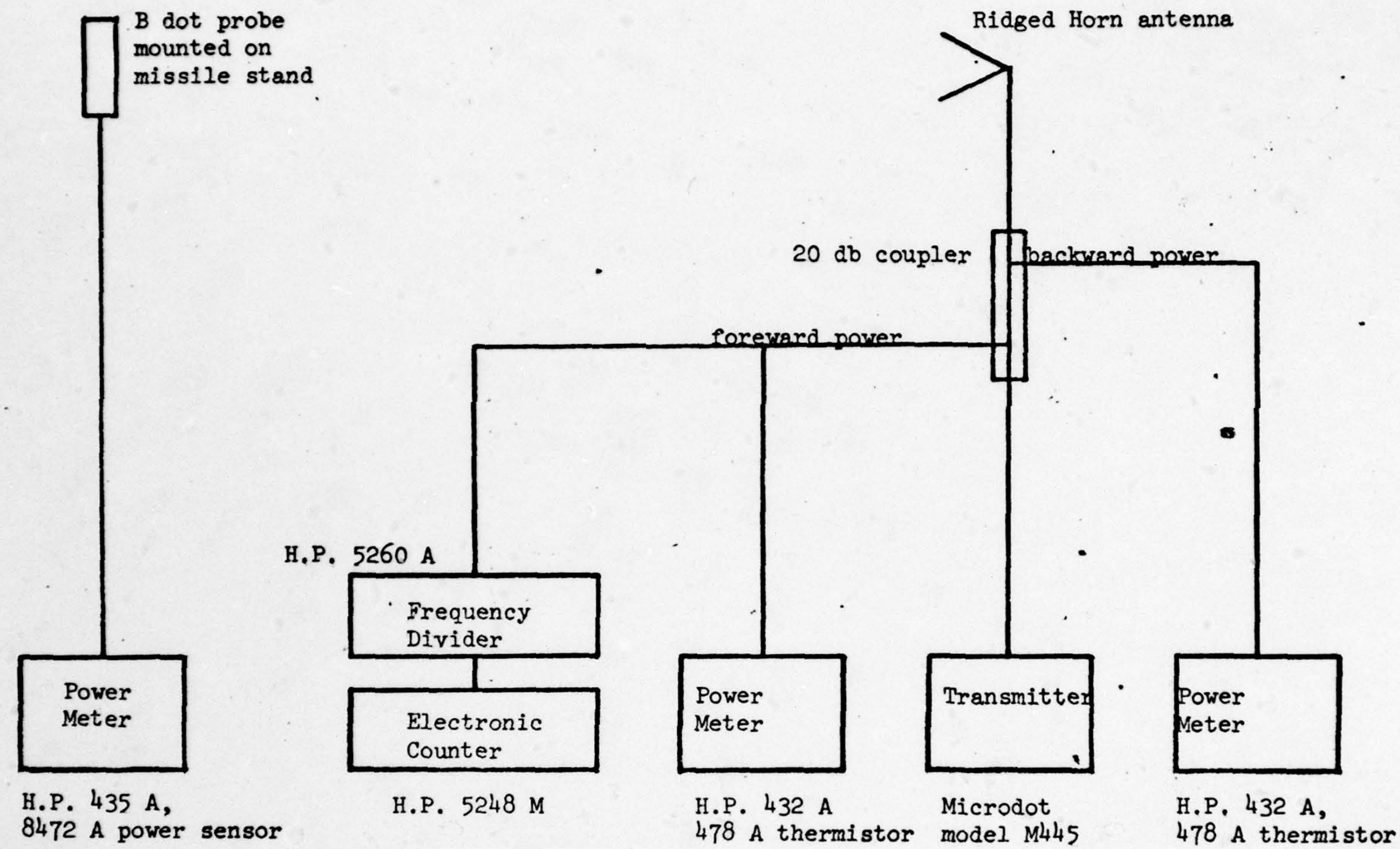

Figure 3. Field calibration instrumentation

Table 3 Calibration factors for ridged horn test range

FREQUENCY (MHz)	k VERTICAL POLARIZATION	k HORIZONTAL POLARIZATION	k 45 DEGREE POLARIZATION
350	4.26	3.65	3.89
360	4.38	3.85	4.28
380	4.36	4.44	4.34
400	4.53	4.59	4.26
420	4.56	3.85	4.08
440	4.65	4.00	4.24
460	4.85	4.17	4.00
480	4.97	4.08	4.08
500	5.0	4.47	4.65
520	5.66	5.16	5.34
540	5.90	5.34	5.08
560	5.10	4.92	5.82
580	5.44	5.70	5.77
600	5.55	5.85	5.90
620	5.70	5.50	5.55
640	5.66	5.44	5.44
660	5.29	5.25	5.16
680	4.92	4.65	5.16
700	4.82	4.65	5.25
720	5.00	4.85	5.66
740	5.30	5.08	5.77
760	5.38	5.05	5.55
780	4.92	4.71	4.92
800	5.20	5.35	5.00
820	5.50	5.55	5.29
840	5.25	4.85	5.85
860	4.85	4.88	6.39
880	5.40	5.50	6.86
900	5.31	5.85	6.56
920	4.85	5.55	5.40
940	4.53	4.74	4.85
960	4.47	4.31	3.70
980	3.85	3.85	3.78
1000	3.54	3.43	3.77
1020	3.56	3.76	4.02
1040	3.59	3.89	4.08
1060	3.41	3.83	4.31
1080	3.92	4.29	4.62
1100	4.14	4.53	4.85
1120	4.26	4.85	5.22
1140	4.47	5.16	5.77
1160	4.71	5.20	5.77
1180	4.78	5.40	5.29
1200	4.36	5.55	5.05

Table 4. Standard Gain Horns

ANTENNA	FREQUENCY (GHz)
Narda Horn 646	1.2 - 1.7
Narda Horn 645	1.7 - 2.66
Narda Horn 644	2.65 - 3.95
Narda Horn 643	3.94 - 5.85
Narda Horn 642	5.4 - 8.2
Narda Horn 640	8.2 - 12.4
Narda Horn 639	12.4 - 18.0

was first pointed directly at the transmitting horn and then tilted 45° toward the earth to measure reflected field amplitudes.

With a missile-antenna separation distance of 18 feet, there is a 5 db field amplitude gradient along the missile when the missile is pointed directly at the antenna. When the missile is broadside to a horn antenna of 14 db gain, the field intensity at the nose and tail of the missile is 6 db lower than the field intensity at the center. Increasing the missile-antenna separation distance will alleviate this situation when more powerful transmitters are available.

The missile stand, which is constructed of a foamed plastic, does not affect the field to any measurable extent in the LP and ridged horn antenna frequency ranges. In the gigahertz region, however, field perturbations due to the stand were observed, as shown in figure 4. With the stand pointed toward the antenna, and therefor presenting a minimum reflecting surface to the incident field, very little in the way of an interference pattern is seen in front of the stand. Interference effects to the rear of the stand do occur, as manifested by a departure of the field intensity contour from a strict 1/r curve. When the stand is rotated 90° and presents a larger reflecting surface to the field, then the interference pattern in front of the stand, caused by a back scattered field, becomes more pronounced. The magnitude of the back scattered field is still very small compared to the direct field, however.

Because of the relatively high directionality of the horn antennas, it was not found necessary to use a diffraction screen to reduce ground reflected fields to 20 db below the direct field. The major field perturbation effect was due to the missile stand. Because of the stand effects, fields near the rear of the missile, for head on illumination, may depart as much as 3 db from a normal 1/r field gradient at some frequencies above a few gigahertz.

Field calibration over this frequency range is done by measuring the forward and reflected power into the horn, using a dual directional coupler near the horn feed point. The short length of cable between the coupler and the horn is calibrated for power loss as a function of frequency. The actual radiated power can thus be determined and the equation for the field power density at the missile is

$$P = P_oG/12.56r^2$$

where

- P = power density in watts per square meter
- P_o = radiated power in watts
- G = antenna gain
- r = missile-antenna separation distance in meters

2.3 On-Launcher Tests

Tests of the response of launcher mounted missiles to an electromagnetic environment have been conducted at the log periodic test site. For

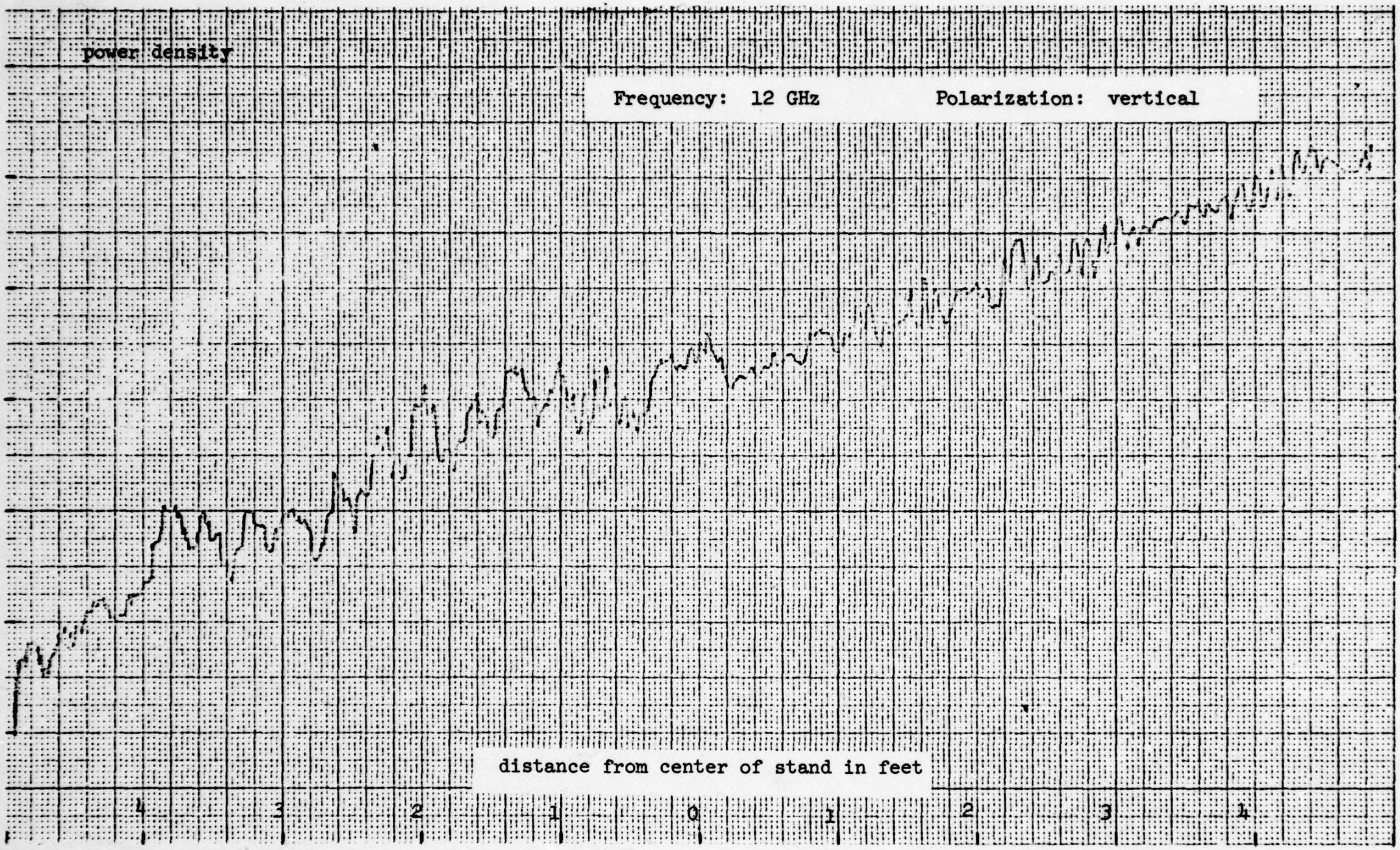

Figure 4 Field map at standard gain horn facility

these tests, it was desired to expose the system to a ground-affected environment, such as might be experienced in a real-life situation. The diffraction screens, used to produce in-flight environments, were therefor removed.

The location selected for placement of the launcher was seventy feet from the LP mast on the center plane of the LP beam. Field mapping and calibration measurements were conducted in the same manner, and using the same equipment as previously described for the in-flight tests at the LP test site. Power density contour data was obtained at a height of 7 feet along a center line from the antenna. Measurements were made at 45 MHz, 90 MHz, and 180 MHz for both vertical and horizontal polarization. Data was also obtained along lines four feet to the left and four feet to the right of the center line, at the same height. In addition, fixed position field density measurements were made at heights of 2, 4, 6, 8 and ten feet at all three frequencies and for both polarizations. The output of a monitor B dot probe, mounted permanently at a position near the LP antenna was recorded during each field mapping measurement. This monitor probe serves as a primary indicator by which the field at the test volume can be adjusted in the future to any desired level. Use of this monitor probe eliminates possible problems such as changing antenna SWR, changes in antenna cable loss, etc.

The results of the field mapping show that the field is quite uniform in a horizontal plane throughout the test volume, varying by less than 3 db. Variation along a vertical line is somewhat larger - as much as 6.7 db from 2 ft. to 10 ft. above the ground. This type of variation is expected for a ground-interacted field arriving at a shallow angle.

3.0 RECOMMENDATIONS FOR RADIATED SUSCEPTIBILITY FACILITIES

Radiated susceptibility programs have been conducted at the U.S. Army Missile Command for a number of missile systems. The principle facility utilized for susceptibility tests has been an open air Electromagnetics test range, augmented by a missile check out laboratory which is used to verify that test missiles meet normal performance specifications. The methodology developed for susceptibility assessment has been tailored to be compatible with the test facility characteristics.

Observation of the susceptibility programs conducted at MICOM, consideration of program objectives, and an analysis of alternate procedures and methodology for achieving the objectives has resulted in the formulation of an assessment methodology which will be more effective, in terms of reduced program time and cost, and provide for the assessment of systems as they progress through the development cycle, rather than only the treatment of end items. The concepts and considerations on which the methodology is structured are discussed in the following paragraphs. The laboratory and test facilities to be utilized in implementing the methodology include a Laboratory Facility and a Chamber Facility in addition to the Open Air and Check Out Facilities. The Laboratory and Chamber facilities are in existence at MICOM, but must be instrumented for the types of investigations they will support.

3.1 Interference Phenomenology

Radiated field interference phenomenology is commonly categorized into "front door" or "back door" interference, with reference to the route by which unwanted energy penetrates into the system. Front door interference takes place by the coupling of energy through system antennas and receptors which have been designed to efficiently collect radiated field energy in some specific frequency band. Interference signals, within the band, are received as efficiently as the signals which the system was designed to receive. Rejection of unwanted signals is achieved through the application of signal processing and discrimination techniques. In some cases, front door interference can occur when the undesired signal is outside the design band pass of the antenna which serves as the port of entry. All antennas will respond with more or less efficiency to out of band frequencies. If the radiated interference field is sufficiently intense, the antenna will transfer energy into the system. For example, the out of band response of antennas is frequently a matter of concern in predicting the effect on a system of the highly intense electromagnetic pulse generated by a nuclear detonation.

Back door interference takes place by the coupling of interference energy into the system through unintentional antennas and receptors. Apertures in the skin of a missile can allow the penetration of interference fields into the missile interior with a resultant generation of voltages and currents in interior cables and circuits. Missile appendages such as control surfaces may act as relatively efficient blade antennas over some frequency ranges. Prior to launch, umbilical cables may exhibit the response characteristics of linear antennas.

Back door interference signals which are within the band pass of the missile system may be processed by the system as legitimate signals with a resultant degradation in system performance. Interference signals outside the band pass of the system can cause system degradation if non-linear processing of the interference signal takes place with a translation of energy into the frequency band of the system.

The discussion and description in this report of a methodology for radiated susceptibility assessment is focused on back door interference. However, the basic assessment principles and considerations apply to front door coupling as well.

3.2 Transfer Function Concept

The interaction of a missile system with a radiated field can be viewed as a sequential process. The series of events in this process are illustrated in figure 5. The first event is the interaction of the field with the missile to produce skin currents on the exterior of the missile air frame and on the control surfaces. The second event is the interaction of the skin currents with apertures in the missile skin to produce internal fields, and/or the flow of control surface currents into the interior of the missile to produce internal fields. The third event is the coupling of the internal fields into cables and circuit leads to produce interference signals at sensitive points in the missile circuitry. The fourth event is the processing of these interference signals by the missile electronics to produce error signals which compete with legitimate signals and which may cause degradation in

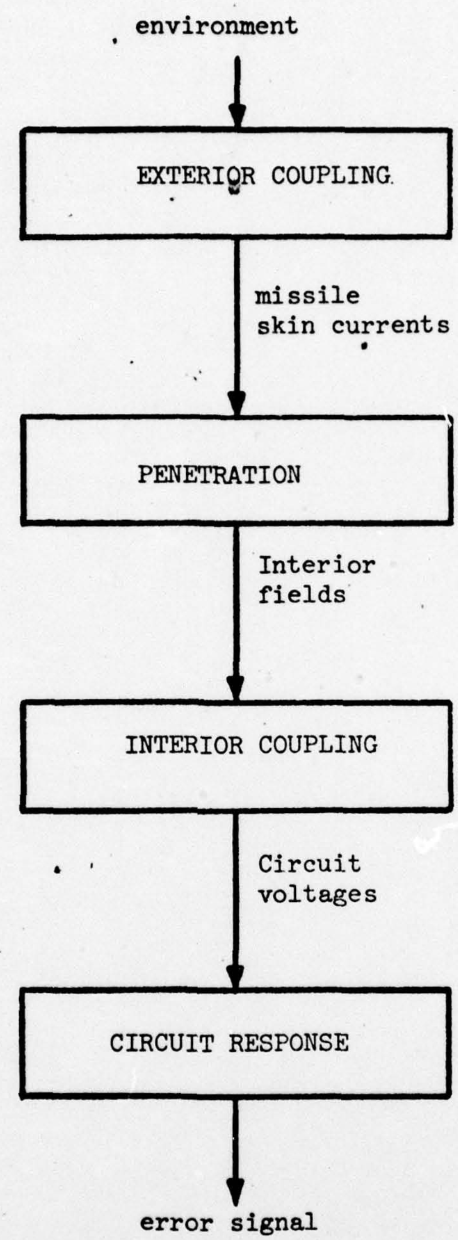

Figure 5. Transfer function concept of missile system response to a radiated environment

missile performance. The error signals appearing in the control loops of a missile are thus related to the radiated field producing the error signals by a set of transfer functions. These are: the transfer function which relates the skin currents to the radiated field, the transfer function which relates the interior fields to the skin currents, the transfer function which relates the circuit signals to the interior field, and the transfer function which relates the error signals to the circuit signals. If these transfer functions could be developed with full rigor, then a complete capability would exist for determining the error signals which would be produced by any given radiated environment. Furthermore, measures which could be applied to reduce susceptibility (reduce error signals) would be made apparent by parametric analysis of the transfer functions.

The term "transfer function," in the context used here, means the causal relationship between an effect (the missile skin current, for example) and a cause (the radiated field). In its simplest form, a transfer function is described by a simple equation between a dependent and an independent variable. Transfer functions developed to predict radiated field effects on missiles, even when very simplified theoretical models are used, are embodied in computer programs. The characteristics of the radiated field (for example) is the input data to the program and the output is the missile skin current.

Theoretical and computational techniques are not developed to the stage where transfer functions can be developed for a specific missile system, in full detail, by purely theoretical analysis. However, transfer functions for skin currents, interior fields, and circuit voltages can be derived for simplified models of missile bodies, apertures, and interior wiring. The transfer functions for these simplified models can be utilized to determine which of the field and missile parameters are of principle importance in the generation of interference signals, to predict parametric dependencies and effects, and to thereby guide the susceptibility testing effort which quantifies the effect of radiated fields on a missile system. An example of the use of a transfer function developed for a simplified model of a missile has previously been described. The work done by Dr. Leonard Tsai, in developing a program to calculate the current generated by a radiated field on a thin wire model of a missile was used not only to specify the missile-antenna separation distance during susceptibility tests, but also to examine the effect of the angle of incidence of the field on the missile skin currents. The results provided guidance in the formulation of the test program.

The essential characteristics of the transfer function which relates guidance and control error signals to circuit interference signals can be determined by a systems analysis of the guidance and control system. Based on these characteristics, predictions can be made of the types of interference signals which should cause the greatest error signals. These predictions will also guide the susceptibility testing effort.

Theoretical and analysis efforts will thus supply some of the characteristics of the system transfer functions and contribute to a more efficient and effective effort. A program of coordinated theoretical, analytical, and testing efforts is the most effective approach for determining the pertinent characteristics of the transfer functions, specifying the susceptibility status of the system, and determining the most practical and cost effective methods of reducing susceptibility.

3.3 Susceptibility Assessment Methodology

A susceptibility assessment program is part of an overall vulnerability program. The susceptibility assessment is conducted to determine the response of a missile system, in terms of performance degradation, to a radiated field environment. All missile systems are susceptible in the sense that, operated in a sufficiently adverse environment, degradation will occur. It is the level of susceptibility that is important. If performance is seriously degraded in environments likely to be encountered, then the system is vulnerable. If degraded only by much more intense environments than can be anticipated, then the system is not vulnerable.

Susceptibility programs should be initiated early in the development cycle so that potential vulnerabilities can be identified and corrective design measures implemented. It is much more cost effective and much more practical to design for survivability than to retrofit for survivability. There are many systems already developed and deployed which still need to be assessed for radiated field susceptibility, however. Assessment facilities, capabilities, and methodology must therefor apply effectively to existing systems and to development systems.

Figure 6 is a flow diagram of a recommended methodology for radiated field susceptibility assessment. This methodology utilizes coupling analyses and system analyses to guide testing efforts which develope quantified error signal data. Engagement simulations are then run, with the environment and scenario dependent error signals entered into the simulation, to determine system effectiveness degradation in terms of changes in the launch boundary for a given kill probability. Vulnerability studies will evaluate whether or not an environment which proves to cause significant degradation in systen effectiveness could actually be encountered. If so, then a hardening (counter counter measure) program is conducted as shown below the double line in figure 6. The data base for the hardening program is developed during the susceptibility assessment program. The double line in figure 6 indicates that hardening efforts are undertaken only if the system is vulnerable.

The coupling analysis shown in figure 6 consists of first identifying system entry ports, where energy may penetrate into the interior of the missile, and circuit entry ports where interference signals generated by the interior fields may appear. Theoretically derived exterior coupling, penetration, and interior coupling transfer functions are then applied to predict the characteristics of interference signals which may appear at circuit entry ports. Parametric analyses are performed to examine the dependence of the characteristics of the interference signals on environmental parameters such as frequency, polarization, and angle of arrival of the incident field. Predictions of the possible circuit entry ports, and the characteristics of the signals that may appear at the ports, are inputs to the systems analysis efforts. The results of the parametric analyses of missile response to the environment are used to structure the environmental radiation tests.

The systems analysis effort shown in the methodology diagram of figure 6 is conducted to determine the relative sensitivities of the circuit entry ports and to describe the characteristics of the transfer functions which relate guidance and control error signals to circuit interference signals. The signal processing characteristics of the system are analyzed to predict

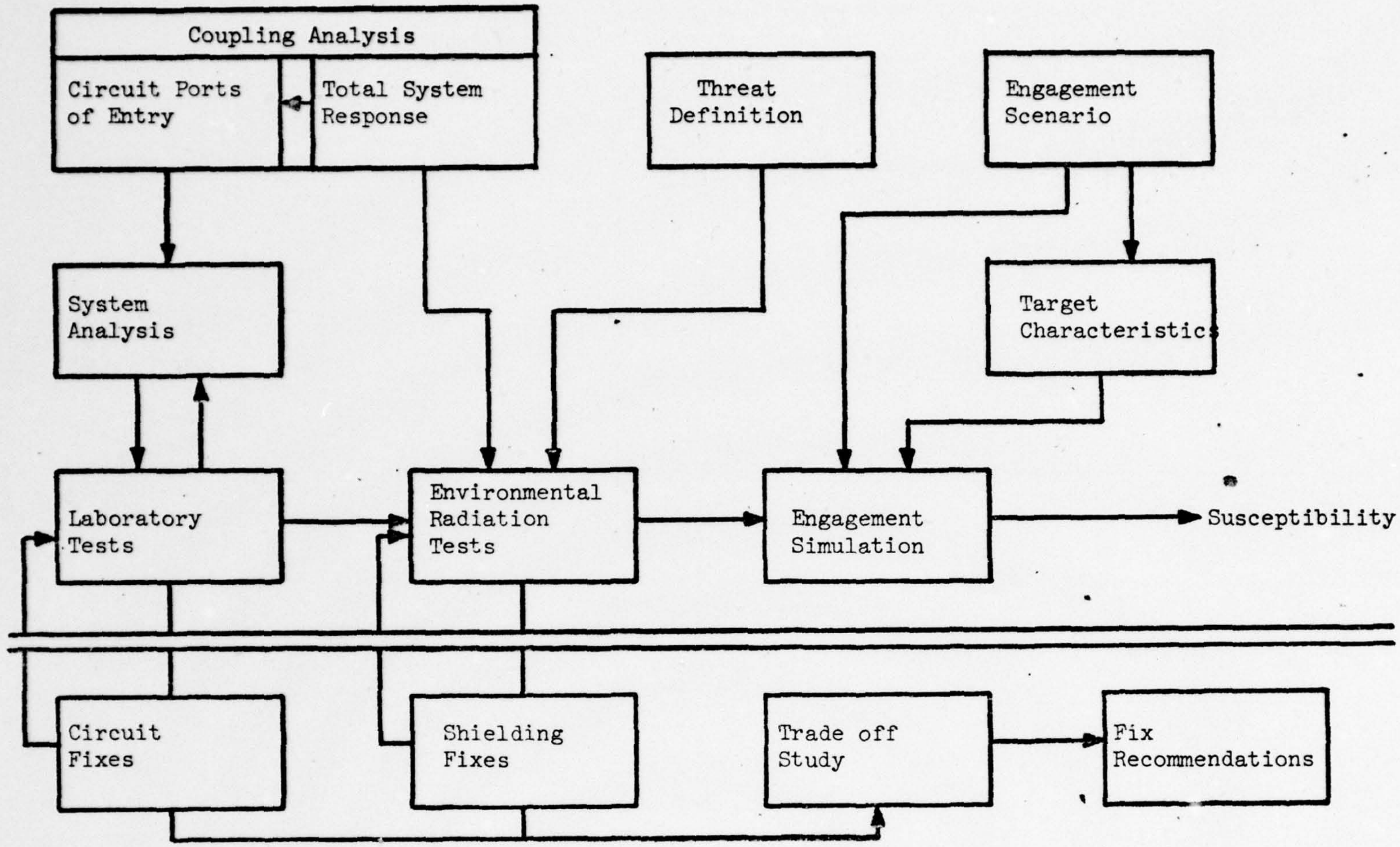

Figure 6 Radiated susceptibility methodology

parametric dependencies between error signal and circuit interference signal. The effects of such interference signal parameters as frequency, modulation type, modulation spectrum, dwell time, duty factor, and signal magnitude are analyzed. The results of these analyses guide the laboratory test program which validates the analyses, provides a more definitive description of parametric effects, and quantifies the effects.

Laboratory tests are conducted in conjunction with systems analyses to determine the system response to interference signals at circuit entry ports. Tests can be conducted on partial systems, such as guidance and control sections and on breadboard systems. In early development stages, lack of system hardware may necessitate the use of breadboards for these tests. Even in the case of fielded systems, circuit points which should be monitored to obtain a description of system response to specific stimuli are not always brought out on the umbilical cable and the most effective procedure is to construct breadboards for testing. Interference signals may be introduced by the direct stimulation of missile sensors or by injection at selected circuit points. The use of a laboratory facility to investigate system response to interference signals is much more efficient that the use of an environmental simulation facility for the same purposes. Conditions are more controlled. Signals can be injected at a specific circuit point or simultaneously at a number of points. The uncertainties that arise in performing these types of investigations in an environmental facility (such as which circuit entry port is responsible for observed effects) are eliminated. Because of the more controlled and versatile situation more complete data can be obtained at a substantially reduced cost and time as compared to use of an environmental facility.

The results of the laboratory tests which characterize error signals in terms of the characteristics of circuit interference signals, and the results of the coupling analyses which predict the effect of environmental parameters on interference signal characteristics, guide the environmental radiation tests. The environmental radiation tests are conducted in a radiated field environment, and under test conditions which simulate a real life situation as far as possible within the limitations of the test facility. In these tests, the total missile system is placed in the test environment. The objectives of the test program are to determine the coupling ports of entry and to establish and quantify the relationship between interference signals and environmental parameters. The environments to be used in conducting these tests are prescribed, to some extent, by threat definition studies of selected scenarios. Testing may be done in other environments which are best suited to parametric studies, for determining ports of entry, or to investigate predicted worst case environment conditions. When the environmental radiation tests are completed, a description and quantification of the system response to a radiated environment will be in adequate detail to perform an engagement simulation. Also an understanding of the coupling mechanisms by which energy penetrates into the system, and the manner in which error signals are generated by the interior energy, will have been developed. Thus if the system is found to be vulnerable, methods of hardening the system can be formulated without further testing. Some limited testing may be desirable to compare the effectiveness and practicality of alternate hardening methods, and verification testing will be required to validate the effectiveness of the method selected for implementation.

3.4 Radiated Susceptibility Facilities

The facilities to be added to those already in existence at the U.S. Army Missile Command in order to support the recommended assessment methodology are described in the following sections.

3.4.1 Laboratory Facility

This facility is to be designed and equipped for the investigation of missile guidance and control system responses to stimuli and interference signals which could be generated by a battlefield environment or by enemy countermeasures. The facility should be equipped for the direct stimulation of missile sensors with both target signals and interference signals, for the injection of signals at sensitive points in the system to investigate the effects of back door coupling, for the detection, aquisition and recording of signals at various stages of processing within the system, and for the analysis of signals in both the time and frequency domain. A full capability should also exist for the measurement of input impedance and transmission and reflection coefficients. This capability is to be utilized for the design and evaluation of system fixes and counter counter measures which involve electrical isolation and decoupling.

The laboratory facility will be employed for investigations of the effect of interference signal modulation characteristics on missile system responses, for establishing the relationship between system response and duration of exposure to an interference signal, for determining the importance and effect of such system parameters as seeker look angle and tracking rate, for investigating the relative sensitivity of possible interference entry ports, for establishing the magnitude of interference signal currents and voltages which cause system performance degradation, and for investigation of round to round variation in system response.

The equipments in the laboratory facility should include:

RF Sweep Frequency Oscillators, covering the frequency range from 50 MHz to 18 GHz. Used as prime signal sources. Sweep capability allows the rapid acquisition of frequency response data.

Pulse Generators, with variable PRF and duty cycle. Used to modulate RF signal and for direct injection of interference signals.

Wide Band Power Amplifiers, covering the frequency range from 50 MHz to 18 GHz. Used when it is desired to expose a system or subsystem to an RF field.

RF Radiators, 50 MHz to 18 GHz, used with power amplifiers to produce RF fields.

Data Acquisition And Recording System, consisting of:

a. An FM telemetry system to transmit missile system diagnostic data from the missile to a receiving and recording station. The telemetry system utilizes an optical data link (fibre optics) between the missile and the receiver station. This eliminates the problem of conducting interference signals into the interior

of the missile via a hard wire data link. The system should have eight IRIG data channels.

b. An eight channel oscillographic recorder and an XY plotter to record and plot the missile data.

c. A fourteen channel magnetic tape recorder.

High Resolution Spectrum Analyzer System, covering the frequency range from .02 Hz to 50 kHz. Includes oscilloscope and plotter display

Associated laboratory equipment including oscilloscopes, 18 GHz universal counter, couplers, power meters, true RMS voltmeters, power supplies, etc.

Target Sources, as required.

3.4.2 Chamber Facility

This facility should be designed and equipped for the investigation of the responses of complete missiles to in-flight interference and counter-measure environments. The environments of concern or interest will be duplicated in the facility. The facility should be equipped for producing plane wave fields with variable modulation characteristics, for the detection, acquisition, and recording of missile response signals, and for the analysis of signals in both the time and frequency domain.

The chamber facility will be used to investigate the effects of radiated field parameters such as frequency, polarization, and direction of arrival. Ports of entry through the missile skin, ports of entry into electronic systems, the relationship between the intensity of the environment and the magnitude of circuit interference signals, the relationship between interference signals and guidance and control error signals, and the effectiveness of hardening and counter counter measure techniques will be investigated in this facility.

Equipments in this facility should be essentially the same as in the laboratory facility. The chamber facility is larger and designed for the production of plane wave environments, which the laboratory facility is not.

The existing open air facility should be used to conduct in-flight tests when highly intense electromagnetic fields are required and when missile-antenna separation distances must be greater than can be accomodated in the chamber facility. The open air facility will be used to conduct all pre-launch tests.